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CONSEIL PERMANENT INTERNATIONAL
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N° 34

Communications du Laboratoire central à Christiania N° 5

FRIDTJOF NANSEN

METHODS FOR MEASURING DIRECTION AND VELOCITY OF CURRENTS IN THE SEA

WITH AN APPENDIX BY DR. V. WALFRID EKMAN

WITH TWO PLATES AND THIRTY ONE FIGURES IN THE TEXT

EN COMMISSION CHEZ
ANDR. FRED. HØST & FILS
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METHODS FOR MEASURING DIRECTION AND VELOCITY OF CURRENTS IN THE SEA

BY

FRIDTJOF NANSEN

During the last few years great improvements have been made in the methods and instruments for studying oceanic temperature and salinity; and it may even be said that considerable success has been attained in these matters. Very good methods for studying dissolved gases have also been found. But before it is possible to come much further in understanding oceanic circulation, it will be very desirable to be able to measure directly movements of the water at different depths in the sea.

It was therefore natural that when the International Central Laboratory was established at Christiania, one of the first problems set to it for solution was the finding of the trustworthy instruments and methods for current-measurements.

It was regarded as essential that instruments should not only register the velocity of the current, but should also as a control, give, at least several, indications of its direction during the period of observation. After several experiments by Dr. EKMAN and the writer two current-meters were constructed, which have both given very satisfactory results. One "The Ekman Current-Meter" (described in *Publications de Circonstance*, No. 24, 1905) registers the velocity of the current by means of a propeller. It has the great advantage of indicating the direction of the current for every 50 revolutions of the propeller. The propeller is mounted on bronze points running in agate bearings. It will as a rule be capable of registering currents with velocities above 2 or 2·5 cm. per second. The other instrument is the one described below.

The Pendulum Current-Meter (the socalled Nansen Current-Meter)

Pl. I, Figs. 1—4

This instrument is based upon the same principle as a pendulum current-meter constructed some time ago, and described by Dr. EKMAN [1]).

[1]) V. WALFRID EKMAN, On a new Current-Meter invented by Prof. FRIDTJOF NANSEN *Nyt Magazin for Naturvidenskaberne*, vol. 39, Christiania, 1901, pp. 163—187.

The instrument which is now made much shorter, is represented in Pl. I, in its present improved form.

Its most important feature is the pendulum Fig. I (P), ending below in a point, and provided with six wings. Owing to the resistance which these wings offer to the water, the pendulum is displaced by currents, more or less according to their strength, and in the direction of the motion of the water.

The pendulum is suspended at the end of a lever (*b*) by means of a screw (*a*). A clock-work which can run for 5 or 6 minutes, turns a wheel (*c*) bearing several teeth (*d*); by it the lever from which the pendulum is suspended is alternately lifted and dropped at certain intervals at a rate of about 5 times a minute. So long as the lever is lifted the pendulum can swing freely and assume its position of equilibrium in the current, but when lever and pendulum drop, the pointed end of the latter falls on to a concave metal disc (*e*) and makes a mark in a thin layer of paraffin wax (or bees-wax and resin) with which its upper concave surface is coated. This disc is, like a compass card, attached to two strong compass-needles (Fig. 1, *n*, they are here seen in transverse section), pivoted on a bronze pin, which is placed perpendicularly under the point of suspension of the pendulum. The disc is easily kept steady and always in the same horizontal position by these heavy needles. The disc itself is graduated into rings of equal width by means of 10 concentric circles, which is again divided by radii into equal segments (Pl. I, Fig. 2). The directions and distances from the centre of the disc, of the marks formed by the pendulum in the wax indicate the direction and velocity of the current measured at the respective moments [1]).

If the clock-work be wound up to run for 5 or 6 minutes about 30 marks are made on the disc. Four discs belong to each instrument. They fit on to the compass-needle in one position only, so that mistake as to the real direction of the current-records are excluded. In order to spare the pin-point of the pivot, the needle with the disc may be arrested by an arrangement shown in Fig. 1; by pushing up *f* the disc is lifted and pressed gently against the ring *g*. This ring which also prevents the disc and needle from being lost in the water, is attached to the compass-box by means of a bayonet-clutch. It has to be unfastened and hung on a hook on the upper part of the instrument (outside the encasement of the clock-work) whenever the disc with needles is being taken out or put in place.

[1]) The displacement of the pendulum from the perpendicular is proportional to the square of the current velocity. If *a* be the number of concentric circles, through which the pendulum has been displaced, and *c* be a constant, which has to be determined for each pendulum, the velocity of the current is given by

$$v = c\sqrt{a}.$$

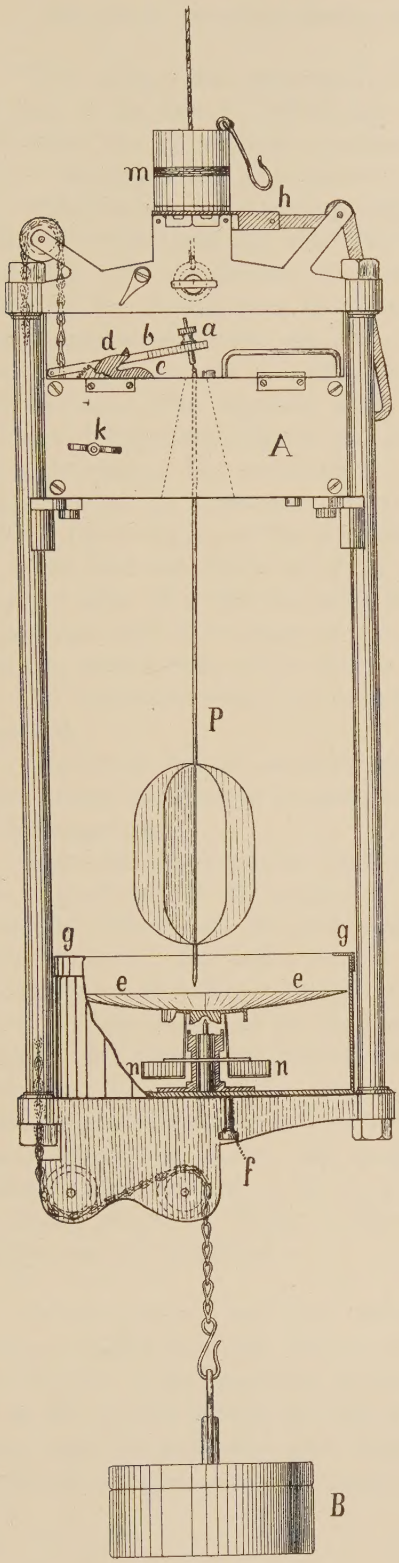

Fig.1

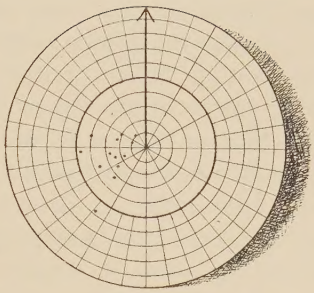

Fig.2

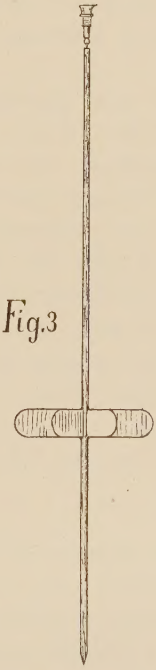

Fig.3

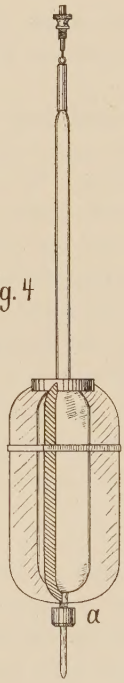

Fig.4

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The clock-work, composed of 3 cogwheels and a regulator, is encased in the box A, which has double lids to prevent disturbing influences due to animals or other objects floating in the water. In Fig. 1 the upper lids are removed so as to show the suspension of the pendulum, and the arrangement of the lever and the second cog-wheel (*c*) with teeth (*d*), the latter protuding through a split in the inner lid. The pendulum rod passes through a conical funnel (indicated by two dotted lines in Fig. 1, A) set in the centre of the clock-work's encasement. On one side of the box is a hole covered with fine wire gauze to let the water in when the instrument is sent down into the sea. The regulator is a pendulum in the form of a solid cylinder horizontally placed and oscillating about its geometrical axis on knife edges. The lower part of this cylinder is made of heavier material than its upper part. In this way the resistance of the water against the swinging of the regulator is reduced to a minimum.

The lead (*B*) which must be able to keep the instrument vertical, in spite of a slow current, also serves to drive the clock-work; it is suspended on a chain carried to the clock-work through one of the two hollow rods of the frame work.

By additional rings (of lead) the weight may be increased as required.

The clock-work is arrested by raising the lever *h*. It begins to work when this lever is pressed down somewhat sharply (by means of a messenger, *m*).

Since the displacements of the pendulum from the perpendicular are proportional to the square of the current velocity the range of velocities which can be measured by one pendulum is of course rather limited. The instrument is therefore generally provided with 3 pendulums of different weight and wing-area: one (Fig. 3) for velocities between 5 and 25 cm. per second; one (Fig. 1, *P*) for velocities between 2·5 and 12 cm. per second; and one (Fig. 4) for very slow currents. The latter is a closed cylindrical glass bulb blown on a glass stem and bearing 4 thin wings of german silver; it floats in water when not loaded. By means of small weights (Fig. 4, *a*) of different sizes screwed on to its end it can be loaded to have any sensibility required. With it currents of 5 mm. per second and upwards may be measured.

Instructions for use. When a measurement is to be taken compass-needle and disc are put in place, and clock-work wound by the key (*k*). The pendulum is then arrested in position as shown in Pl. II, Fig. 1. To do this the wheel *c* (Pl. I, Fig. 1) is turned with the finger until the pendulum just drops (care being taken that it does not touch the compass disc); the point of the pendulum is then guided and

stuck into a hole made in the ring *g* for the purpose. The wheel *c* is then turned backwards (easily done if the instrument be gently shaken so as to make the regulator oscillate) until the lever of the pendulum is wedged fast under the tooth *d*. In this position of the pendulum the upper opening of the funnel through the clock-work encasement will be closed. Finally the clock-work is arrested by raising the lever *h*.

When everything is ready the compass-needle with disc is made free by lowering *f*, and the instrument then lowered into the sea with a little caution and sent down to its place. As soon as it has probably come to rest a messenger is sent down to set the clock-work working, and after eight minutes the apparatus may be hauled up. The compass-disc is changed for another which is kept ready, the instrument is again put in working order, as mentioned above, and sent down to take another observation if desired.

In the meantime the direction and magnitude of the displacements of the pendulum recorded on the first disc, are either noted, or the marks may be copied on a paper ruled as the disc itself (Pl. I, Fig. 2). This done, the marks in the wax-coating are effaced and the wax smoothed with a warm knife. In this manner the same wax-coating may be used repeatedly. When it is necessary to renew it, warm the disc over a lamp, take away the melted wax-cover, and clean with a cloth. Put on new wax (about 2 grams is a suitable quantity), warm, and move the disc so as to distribute the melted wax evenly; then cool the disc suddenly by lowering its under side into water, or by directing a jet of water against it. After some practise a fairly uniform and transparent layer may be obtained in this manner, though always somewhat thicker near the centre than near the circumference of the disc.

Accuracy of observations. It is unfortunate that owing to the frame of the instrument, its position with respect to the direction of the current has an appreciable influence upon the results of the observation; and this position cannot be known. By experiment it has been found that, if the instruments be so placed that the direction of the current makes an angle of 90° with the plane of the two vertical rods of the frame-work, the pendulum will indicate velocities which are about 25 % greater than those indicated when the same current runs parallel to the plane of the frame. If the mean of these two extreme indications be accepted as the true value, it is apparent that there may always be an inaccuracy in the observations of about $\pm$ 13 %. If, for instance, a mean velocity of 7 cm. per second be found, the right value might actually be anything between about 6 and 8 cm. per second.

The frame work of the instrument may also have some disturbing influence upon the direction of the current.

Oscillations of the pendulum, always irregular. The pendulum will always oscillate more or less irregularly in the current, although the latter itself may be quite regular and steady; the marks the pendulum makes on the compass disc, during one observation, may therefore be scattered somewhat irregularly over a small area on the disc. Their mean value is therefore taken as indicating both the direction and velocity of the current. By experiment it has been found, that the medium pendulum (Pl. I, Fig. 1 *P*) in a steady current with a velocity of about 7·6 $^{cm.}/_{sec.}$ oscillated about 15° to both sides of the true current direction (*e. g.* between S 10° W and S 40° W, the current was consequently running towards S 25° W), and between the third and the fifth concentric circle (the mean was actually about 3·6). It is apparent that pendulum oscillations of this kind do not indicate real irregularities in the actual movement of the water.

By many observations and especially near the bottom of the sea the present writer has, however, observed much greater irregularities which were undoubtedly due to irregularities in the water-movements.

If the instrument be suspended by a long line from the sea-surface *e. g.* from the ice, it is of course necessary to be careful that the instrument does not perform pendulous movements, and it is therefore generally necessary to wait a good long time after the instrument is let down into place, before the messenger is released. There is also the possibility of this messenger bringing the instrument into pendulous oscillation. And if there be a strong surface current, it may produce vibrations in the line, and thus make the instrument move.

It may be stated that there are now current meters capable of fairly well satisfying present requirments, so fas as the instruments themselves are concerned[1]). The chief question now remaining is therefore the finding of satisfactory methods for using the instruments.

There seem to be chiefly two courses open:

1) The most natural method is to try to arrange as nearly as possible a point of fixture from which the current-meter may be

[1]) Prof. Otto Pettersson has constructed a current-meter chiefly calculated to be used on board light-ships. It is described in *Publications de Circonstance*, No. 25, 1905. It has given very satisfactory results; but as it has a bifilar suspension, it can only be used down to a limited depth. Just now I also receive *Publications de Circonstance*, No. 30, in which Mr. R. J. Witting describes a bifilar current-meter with electric registration. It would naturally be a great advantage to be able to read off the velocities and directions continually on deck while the observations go on, but as the instrument has a bifilar suspension and as the electric cable has moreover a diameter of 9 mm., its use will necessarily be reduced to very moderate depths.

suspended so that its own motion is a negligeable quantity. The indications of the instrument may then be regarded as a fairly accurate measure of the current.

2) The instrument may be suspended from a moving point (ship, drifting ice, etc.) the movement of which has, however, to be accurately determined simultaneously with the current-measurements. In this case the indication of the current-meter has to be reduced by a quantity depending on the motion of the point of suspension, in order to obtain the actual velocity and direction of the current measured.

1. Current-meter suspended from a Point of Fixture

A. Bottom-currents

Near the bottom of the sea a point of fixture is easily attained by anchoring the instrument on the bottom. Bottom-currents are therefore comparatively easy to measure. The Pendulum-Current-Meter is especially convenient for this kind of observations. It may be suspended in two manners: either upon a tripod resting on the bottom, or by Anchor and Buoy.

a) The Measurement of Bottom-Currents with Pendulum-Current-Meter and Tripod

A tripod (see Pl. II, Fig. 1) was constructed of strong oak; the legs (*a*) were 1·75 metre long and were movable on hinge at the top. The cross-bars (*b*) were 1·4 metre long; each was hinged at one end and had a screw fastening at the other, so that the tripod itself could be folded up when the ends of the cross-bars were unfastened. Leads were fastened to the lower ends of the legs, at *c*, in order to make the tripod sink well in the water, and stand steady on the bottom. As a rule leads of about 10 kilograms on each leg were used; if the depth be great they ought of course to be heavier. From the top of the tripod the current-meter is suspended from a hook and is well fastened so that it cannot become unhooked if the tripod happen to upset on the bottom, as once happened to the writer, with the loss of an instrument as the result. The suspension itself which is made of wire rope is taken shorter or longer according to the distance above the bottom at which the current-meter is desired. Along this short wire-rope a messenger (Pl. II, Fig. 2, *m*) runs which may be suspended from a hook (Pl. II, Fig. 2, *h*) underneath the top of the tripod. From this hook the messenger is released by another messenger which comes down the sounding line from the sea-surface, and presses down the rod *a*, and thus the current-meter may be set working.

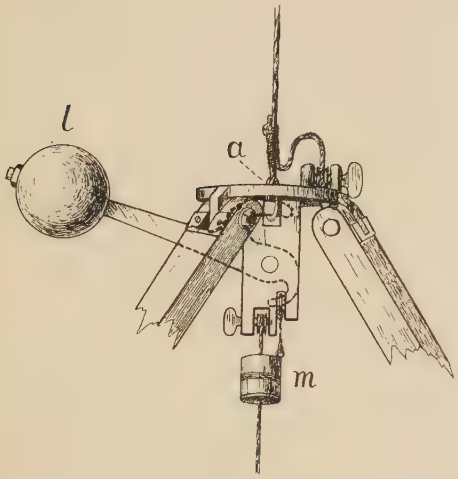

Fig. 3

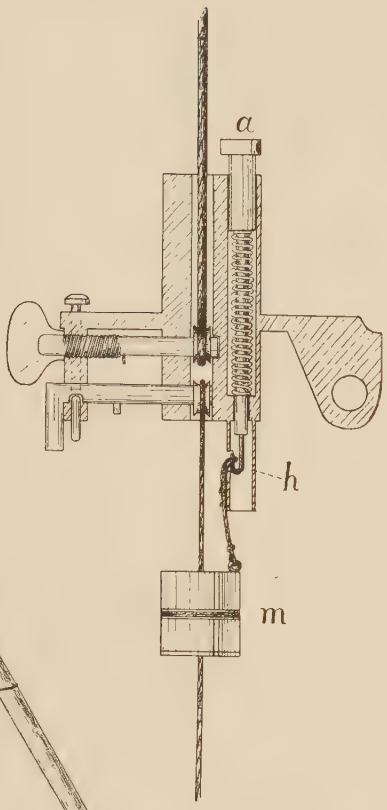

Fig. 2

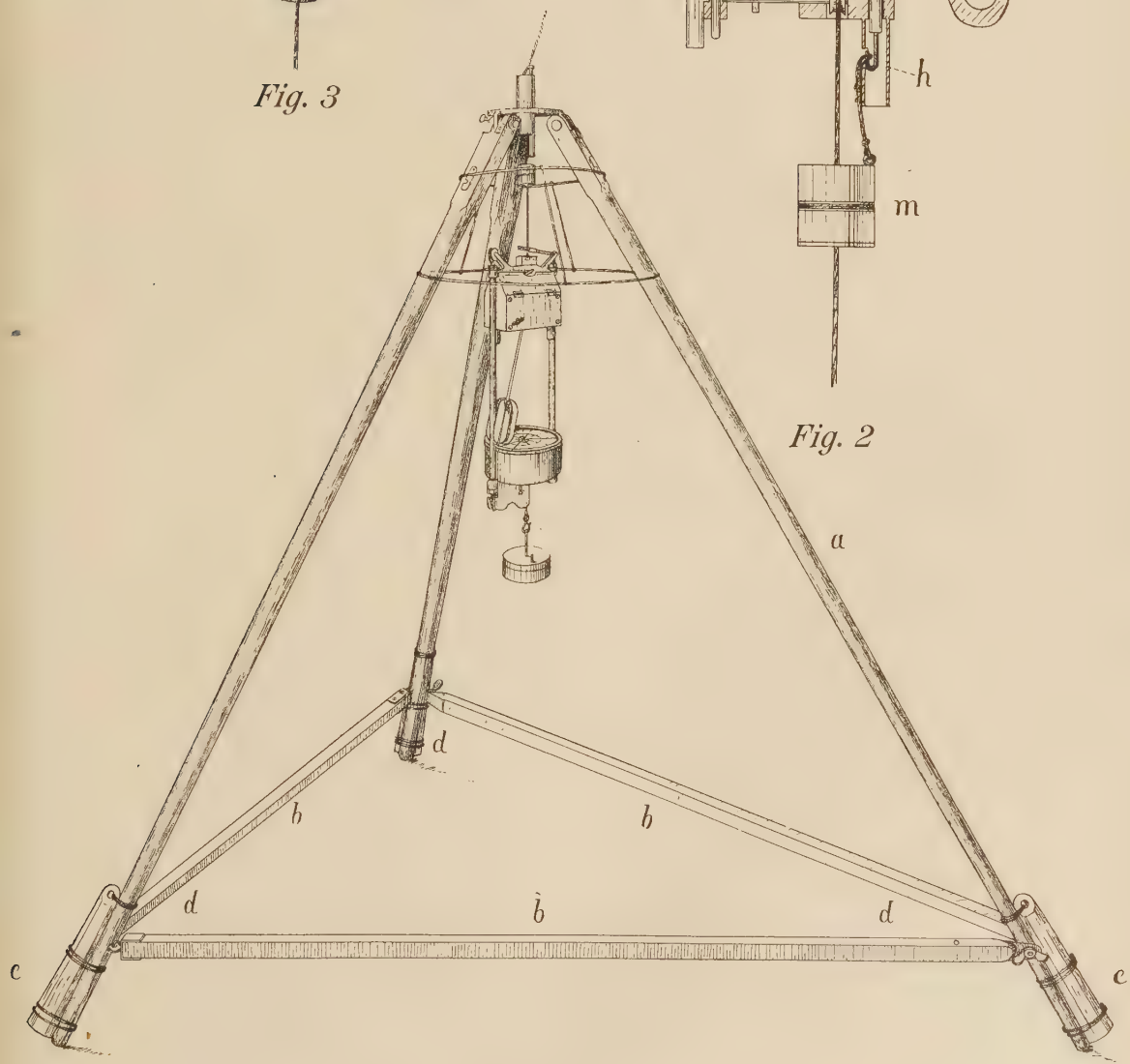

Fig. 1

This kind of release is the best, whereever practicable; the observer is quite free to start the instrument at any moment he may desire after the tripod has once reached the bottom.

Under certain circumstances it may, however, be desirable to have an arrangement which releases the current-meter automatically as soon as the tripod reaches the bottom. An automatic releasing arrangement of this kind is given Pl. II, Fig. 3. As soon as the weight of the tripod rests on the bottom the ring *a* becomes unhooked, the lever *l* falls and releases the messenger (*m*) of the current-meter.

Round the upper end of the tripod are several rings of thick brass wire (Fig. 1), to prevent a loop of the sounding line, when slack from getting between the legs of the tripod and disturbing the current-meter. Before this necessary arrangement was introduced, it once happened that a loop of the line got around the current-meter, and nearly severed its suspension, when the tripod was hauled up.

If the bottom is very soft special precautions may have to be taken to prevent the tripod from sinking too deeply into the mud. Pieces of canvas may be fixed in the corners between the cross bars (at *d*). This canvas has, however, the disadvantage of offering much resistance to the water when the tripod is lowered or hauled up. Instead of canvas a strong metal net-work may therefore be used, if this net-work fills the whole area between the cross bars it may also have the further advantage of preventing medusæ and floating sea-weed from coming near the current-meter and possibly adhere to the pendulum on its way down. As, however, this net will offer some resistance to the water the tripod has to be lowered somewhat more slowly, lest it be upset. It is also possible that this network might occasionally give the tripod a more unsteady position on the bottom, especially if it hits a stone.

The mode of operation employed by the writer when using the tripod is generally the following. It is lowered fairly rapidly till it comes near the bottom, then it is stopped to let the tripod sink and stretch the line out fully. To make sure that the tripod comes down standing, it is now lowered slowly till it rests on the bottom. The messenger is then sent and the line held tightly with the hand until it is felt or heard [1]) that the messenger has reached the tripod. The line is then loosened and kept perfectly slack while the observation lasts.

Where the bottom is very soft the tripod may find a less stable position, and if great care be not taken may possibly be moved or rocked by pulls in the line due to the drifting or swaying of the ship,

[1]) If the depth be so great that this cannot be directly ascertained I would recommend to use an automatically releasing arrangement as described above; but the line must then be kept perfectly tight the whole time during the lowering of the instrument.

but otherwise observations taken with the tripod are always very reliable; and on hard bottom pretty strong impulses through the line are necessary to make the tripod rock.

Observations with tripod may be made with ease from an anchored vessel; but it is not absolutely necessary to anchor, especially if the tripod be provided with an automatic releasing arrangement. In this case the tripod is simply lowered to the bottom, with care, and so that it comes down standing as soon as the ship has stopped dead. The line is kept perfectly slack after the tripod has reached the bottom, and the vessel is kept as nearly as possible at the same spot so long as the observation lasts. Finally the instrument is again hauled up. It may happen that the first marks made by the pendulum after the arrival of the tripod on the bottom, may be somewhat erratic; the water may have been stirred by the arrival of such a big instrument, and the latter may not have found its final stable position at once. The great majority of marks will, however, give the real bottom-current.

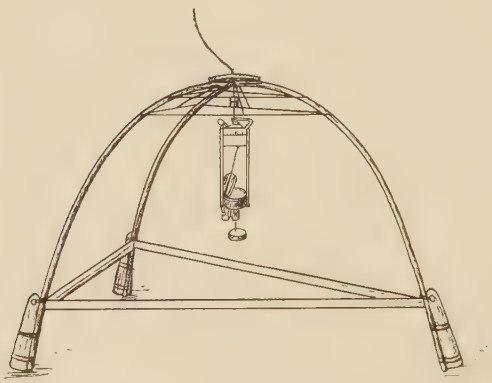

Fig. 1

The legs of the tripod will naturally produce local irregularities in the motion of the water and consequent inaccuracy in the observations. It will make a difference how the tripod is placed in relation to the direction of the current: whether a leg or an open side be turned towards it. Hitherto there has been no opportunity of examining the inaccuracies that may be thus caused. To reduce them it would be an advantage to make the tripod of thin metal rods or tubes; but this would add to the cost. Iron might also be used, but in that case the legs of the tripod ought to be bent (Fig. 1) so as to prevent the iron from coming to near to any possible position of the current-meter and thus disturbing the compass needle.

By the above method with tripod and pendulum current-meter, it has been possible to make investigations on the movements of the water near the sea-bottom. These movements are of interest not only to the oceanographer but also to the geologist and geomorphologist, whom they specially interest hy reason of their great importance in all questions involving the deposition and distribution of sediments or the erosion of the sea-bottom. By means of this apparatus it is

also possible to study motion near the bottom due to surface wave-motion, and to determine the depth at which this effect is still appreciable; a subject which is of much importance to geomorphologists, and which is still much debated, no trustworthy direct observations having been hitherto made.

b) Measurement of Bottom-Currents with Pendulum Current-Meter and Anchored Buoy

Currents near the bottom, above the levels within the scope of a tripod, may be easily studied by the pendulum current-meter if it be suspended by means of anchored buoy (see descriptions of method below pp. 23—26). The writer has been able to take observations of currents near the bottom of some value at least, by means of a buoy, attached to the line near the sea-surface and which was directly connected with the vessel by a slack line (see later); if the current-meter be placed only a comparatively short distance above the sea bottom, the possible movements of the buoy in this arrangement will cause only a very small motion of the instrument. If, for instance, the sea be 200 metres deep, the buoy placed near the sea-surface and the current-meter 10 metres above the bottom, a movement of the buoy with a velocity of 20 $^{cm.}/_{sec.}$ will move the instrument 1 cm. per second, and an inaccuracy of $\pm$ 1 $^{cm.}/_{sec.}$ will be thus produced.

As, however, the water-movements near the sea-bottom are often extremely slow, errors of this magnitude may be disastrous to the observations; and it is therefore decidedly preferable to have no direct connection between the buoy and the sea-surface, while the measurements are being taken, so that the buoy is left entirely to itself to find its position of equilibrium. One of the two methods described later (pp. 24—25) may be used. These methods with the buoy attached to the end of the line have the advantage that it is not necessary to anchor the vessel.

B. Intermediate and Surface Currents

Ice-covered fjords. Where the sea is covered with landfixed, motionless ice, as in many Norwegian fjords during the winter, it is easy to measure the velocity of the currents at all depths of the sea. The instruments may simply be lowered down through a hole in the ice and may be kept sufficiently motionless.

The writer's first experiments with current-measurements were actually performed in this manner on the Christiania Fjord several years ago with the first pattern of pendulum-current-meter. And Dr.

Walfrid Ekman made an interesting series of observations with the same instrument during the spring of 1901 [1]).

Anchored ship. It is, however, comparatively seldom that it is possible to get such favourable conditions as land-fixed ice. As a rule it is necessary to make the observations from a ship or boat, and then the real difficulties begin. The simplest method would naturally be to anchor the vessel, and to lower the instruments from it direct. This method has hitherto been used by almost all oceanographers who have tried current-measurements with more or less success. But a ship anchored with a simple anchor will always sway, and thus perform movements which will make the measurements of the currents more or less inaccurate and uncertain; and the greater the depths at which the ship is anchored the greater will be the movements of the ship, and the less trustworthy the observations. Sometimes the ship may even drag its anchor, and this may be difficult of control if the depths be great; and the observations taken may be of still less or no value and misleading.

To make experiments on more trustworthy methods for making current measurements Dr. Ekman and the writer made a cruise with the Michael Sars in the Skager-Rack in the summer of 1903, when Dr. Hjort was kind enough to place the ship at our disposal for several days for this purpose. We did not, however, arrive at any satisfactory results then, except that the method of measuring bottom-currents by means of the tripod, proved successful. In the summer of 1904 the writer, therefore, undertook a longer cruise with his yacht "Veslemöy" which had been specially fitted out for the purpose. The yacht is about 32 register tons, about 50 feet long on the waterline, and draws about 9 feet on the keel. It is rigged as a fore and aft schooner, and has an auxiliary steam engine. Three great hand winches, each with about 1000 metres wire rope, for anchoring the vessel, were installed and besides these a few smaller hand winches with thinner steel and bronze-line for the current-meter were placed on deck. It also had a good selection of anchors and grapnels of different sizes.

Fig. 2

The first plan in 1904 was to try whether it would be possible to keep the vessel fairly motionless by using several anchors.

The experiments were made in the Drammen Fjord (June 1904), where there was an insignificant surface-current and no considerable wind. First two bow anchors or grapnels at depths of a little more than 100 metres, were tried. The anchors were placed apart at a con-

[1]) V. Walfrid Ekman, On a new Current-Meter invented by Prof. Fridtjof Nansen. *Nyt Magazin for Naturvidenskaberne*, vol. 30, Christiania, 1901, pp. 163—187.

siderable distance from each other (see Fig. 2); but the vessel moved and swayed in spite of the anchors, especially where the wind shifted, and the result was not satisfactory. It was also difficult to make the grapnels hold in the soft bottom, although they had been specially constructed for the purpose. One heavier bow anchor and one stern anchor (see Fig. 3) were then tried, and the anchor lines tightened as much as possible. But even then the vessel would sway towards each side, and it was moreover owing to the increased strain in the anchor-lines still more difficult to make the anchors or grapnels hold, and the vessel would easily drag its anchors[1]).

Fig. 3

The best plan would naturally have been to have two bow-anchors (like Fig. 2) and one stern anchor (like Fig. 3) at the same time; but as it would be very complicated and require much time to use so many anchors, and as on the whole the use of several anchors is very troublesome, especially at greater depths, the idea was given up and it was considered more profitable to experiment with other methods.

The result of all these experiments is, that the writer cannot recommend current measurements made directly from an anchored ship, unless special precautions be taken to determine accurately the movements (both direction and velocity) of the ship while the observations are made. Where, however, the depths are not very great, and

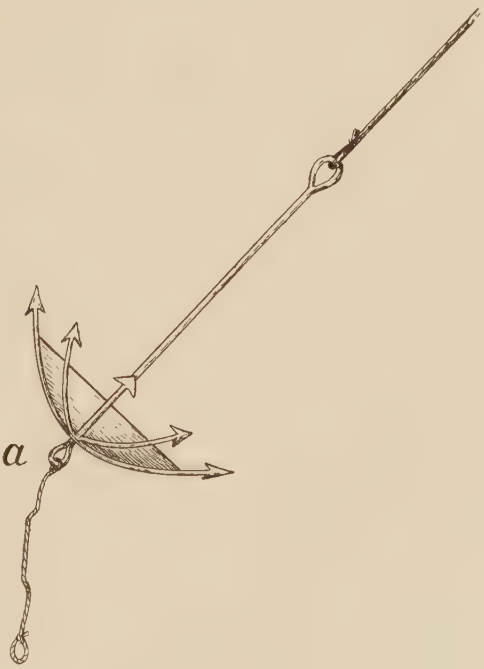

Fig. 4

[1]) For soft bottom grapnels of the form illustrated in Fig. 4, are recommended. The branches of the grapnel are united by a thick plate of iron, which digs into the mud, and gets a good hold. They have the disadvantage of being often heavy to get loose from clayey bottoms, and they may bring up much mud or clay with them. They have therefore to be well cleaned before they are taken on board, and for this purpose a ring with a short rope at the lower end (*a*) is practical. By means of this rope the grapnel may be turned upside down, and the mud emptied from the hollow of the iron plate, while in the water.

where there is a strong and steady surface-current stretching the anchor-line and keeping the ship comparatively steadily in a certain position, and without much swaying, fairly trustworthy observations of strong currents in the upper layers of the sea may be made. But if the currents to be measured, are slow, as for example in the deep layers of the sea and near the bottom, observations taken directly from an anchored ship are of very little or no value.

Where there is no strong surface current to keep the ship steady, its movements may become very irregular, and no current-observations of value can be made unless special precaution be taken to determine the movements of the vessel. To trust the wind for keeping the ship in a steady position is not at all to be recommended.

A few examples may be useful to show how easy it is to be mislead by observations of this kind:

On June 20, 1904, the "Veslemöy" was anchored by two bow grapnels (spread out a good distance from each other as in Fig. 2) in the Drammen Fjord. The depth was 116 metres; bottom soft mud. There was a moderate wind blowing from NW. Three observations were made at a depth of 4 metres below the surface with EKMAN's current-meter, with the following results:

Drammen Fjord, June 20, 1904

Hour	Depth in Metres	Duration of Observation	Number of Revolutions of Propeller	Apparent Velocity of Current measured	Indications of Direction of Current[1])
3 p. m.	4 m.	10 minutes	843	34 cm./sec.	1 S 70° E 2 S 80° E 1 N 60° E
3·18 p. m.	4 -	5 —	105	9 —	1 N 30° E 1 S 60° W
3·29 p. m.	4 -	5 —	49	4·5 —	1 S 10° E

These observations merely indicate the movements of the vessel. The current was in fact quite insignificant, only a few centimetres per second, and did not change during the observations. During the first observations the vessel has partly dragged her anchors before the wind (towards S 70° E and S 80° E) and partly swayed towards starbord (N 60° E). During the second observation the vessel has evidently swayed, partly towards starbord (N 30° E) and partly towards port (S 60° W) giving an apparent current of 9 cm. per second. During the last observation the vessel has moved very little. But during none of these observations could the movements of the ship

[1]) Direction of current means always the direction from which the current came, when not otherwise stated.

be noticed on board except by special arrangement made for the purpose (see later), although in one case an apparent result was obtained of as much as 34 cm. per second, which is no insignificant current, as it means 1·2 kilometres per hour, or 29 kilometres in 24 hours.

In the middle of June, 1904, the "Veslemöy" was anchored by one grapnel in the inner Christiania Fjord, between Næsodden and the Fornebo Peninsula, at a depth of 68 metres. A moderate southerly wind was blowing. There was a surface-current running before the wind, towards NNE.

The following observations were taken with EKMAN's Current-Meter:

Inner Christiania Fjord, between **Næsodden** and **Gjeita**, June 1904

Hour	Depth	Duration of Observation	Number of Revolutions of Propeller	Apparent Velocity of Current measured	Indications of Current-Direction
5 p. m.	2 metres	6 minutes	174	12 $^{cm.}/_{sec.}$	2 S 60° W 1 S 50° W
7·32 -	3 —	5 —	106	9 —	1 S 20° W 2 S 30° W
7·10 -	4 —	6 —	128	9 —	1 S 50° W 1 S 60° W
6·59 -	5 —	5 —	132	11 —	3 S 80° W
5·22 -	10 —	10 —	105	5 —	2 N 20° W 1 N 30° W
6·49 -	10 —	5 —	22	2·5 —	No indication.
7·45 -	10 —	5 —	0	0 —	0
7·52 -	10 —	12 —	296	10·5 —	1 E 3 N 80° E 1 N 70° E 1 N 60° E
5·42 -	20 —	10 —	68	3·3 —	1 N 20° W
6·00 -	30 —	12·5 —	184	6·5 —	1 S 10° E 1 S 40° W 1 S 70° W 1 S 80° W
6·30 -	10 —	10 —	57	2·9 —	1 W
Bottom	68				

Near the same place, where the vessel was first anchored, the bottom-current (0·70 m. above bottom) was determined (by tripod) at a depth of 44 metres to be 3 $^{cm.}/_{sec.}$ coming from N 55° E, at 3·50 p. m. This was, however, on a rocky shoal where the current was much stronger, than near the bottom at the above place with a depth of 68 metres.

Some of the above observations seem to be fairly accurate, and

the vessel has evidently had no great motion. The observations from 3, 4, and 5 metres, taken between 6·59 and 7·32 p. m., seem for instance fairly probable, with the exception that the velocity at 5 metres was higher than at 3 and 4 metres. The observation from 2 metres seems also fairly probable, whilst those from 10 metres and deeper are not trustworthy, and swaying of the vessel has evidently caused great irregularities. The observation near the bottom, at 66 metres, was taken while the vessel seemed to be fairly quiet.

As, however, it is seen that swaying of the ship has caused such errors as are evident at 10 metres (7·52 p. m.) and 30 metres, it is impossible to say which observations are trustworthy, and the whole series is consequently of no value.

On July 22, 1904, the "Veslemöy" was anchored by one anchor in 91 metres of water in the Frier Fjord (near Porsgrund). There was very little wind and the conditions for current-measurements seemed very favourable. A series of observations were taken with the EKMAN current-meter, at first directly from the anchored ship, and later, as a control, indirectly by means of an anchored buoy. The results were the following:

Frier Fjord, July 22, 1904

	Hour	Depth	Duration of Observations	Number of Revolutions of Propeller	Apparent Velocity of Current measured	Indications of Direction of Current
Direct Observations without Buoy	4·05 p. m.	3 metres	5 minutes	98	8·5 cm./sec.	1 N 20° W 3 N 30° W 4 N 40° W
	4·20 —	5 —	16 —	452	12 —	3 S 10° W
	4·44 —	4 —	16 —	253	7 —	1 N 20° W 1 N 30° W 2 N 40° W 1 N 50° W
	5·11 —	7 —	10 —	247	10·5 —	1 N 40° W 2 N 60° W 1 N 70° W 1 N 80° W
Observations taken with anchored Buoy	6·30 p. m.	10 metres	15 minutes	0	0	0
	7 —	5 —	16 —	0	0	0
	7·30 —	5 —	10 —	50	2·6 cm./sec. [1])	1 S 1 W
	7·50 —	20 —	10 —	0	0	0
Without Buoy	8·15 —	20 —	5 —	58	5·2 —	1 E

[1]) During this observation the buoy had come in under the vessel, which swayed westwards, and thus carried the buoy along with it.

The first series of observations made directly from the vessel, and without a buoy attached to the line, gave, as it seemed, fairly satisfactory and probable results, if it had not been for the observation taken at 5 metres, which gave a contradictory direction of the current.

When, however, the control-observations were made by means of the same current-meter, anchored from a buoy, it was clearly proved, that the former observations were valueless, and merely due to the movements of the vessel, whilst the actual movements of the water were so slow that they could not be registered by this particular instrument. As final evidence that such was the case a new observation at 20 metres was taken without buoy, and a new record was again obtained due to the movement of the ship (see Table above).

The following example may be mentioned as evidence that current-observations of some value may be taken from an anchored ship, when there is a strong surface-current to keep the vessel fairly steady, and no very strong wind to disturb her.

On July 27, 1904, the "Veslemöy" was anchored in the Skager Rack, on the edge of the Norwegian Submarine Channel off Risör. The depth was 154 metres. The vessel was swaying a great deal, as was seen by a buoy, which was put out for some time. The following observations with the Ekman Current-Meter were made while the vessel remained fairly steady.

Norwegian Channel, July 27, 1904

Hour	Depth	Duration of Observation	Number of Revolutions of Propeller	Apparent Velocity of Current measured	Indications of Direction of Current
8·20 p. m.	0·2 metres	5 minutes	728	59 cm./sec.	1 N 40° E 5 N 50° E 8 N 60° E
8·45 -	25 —	5·5 —	538	40 —	Observation spoilt by accident.
8·35 -	50 —	5 —	252	21 —	5 N 40° E
9·45 -	50 —	5 —	282	23 —	5 N 40° E
9·15 -	80 —	7 —	178	11 —	3 N 30° E
9·30 -	100 —	5 —	91	8 —	3 N 30° E
9·00 -	120 —	4·5 —	28	2·5 —	1 N 30° E

Simultaneously with the observation at 0·2 metre, several observations of the surface current were made by means of pieces of paper thrown into the water and allowed to drift a measured distance along the sides of the vessel. The velocities of the surface-current thus obtained were between 62 and 68 cm. per second.

The bottom-current (75 cm. above the bottom) at a depth of 154 metres, was measured with the pendulum current-meter and tripod; this bottom-current was somewhat irregular. Most marks indicated a water-movement from S 45° E with a mean velocity of about 2 cm. per second, whilst two marks indicated a water-movement from N 20° W of between 3 and 4 cm. per second.

The above observations with the EKMAN Current-Meter, directly from the anchored ship, seem to give very probable results, although they are certainly not accurate as the vessel was moving, at least a little, while they were being taken. Particularly the observations from greater depths, 80 to 120 metres, are untrustworthy, although, strange to say, they all give exactly the same direction of the current, and velocities gradually decreasing downwards. The observation from 120 metres are not to be regarded as accurate, as the current-meter could hardly register currents of such low velocity. It shows, however, that, at least during this observation, the vessel has not moved so much as to make the observation of the higher velocities very uncertain.

Recommendation for making current-measurements directly from anchored ship. Simultaneously with the observations of the stronger currents, another EKMAN Current-Meter should be lowered down into quiet water near the bottom, where the velocities of the currents are seldom more than a few centimetres per second; as may be ascertained by means of the Tripod and the Pendulum Current-Meter. The lower current-meter will indicate approximately how much the ship has moved and in what direction, during the time of observation, and this result may be used for correcting the values obtained by the current nearer the surface.

Another method of determining the movements of the ship is to let a long pointed and heavy lead run out rapidly, right down into the mud at the bottom, and let the lead remain fixed there during the whole series of observations. By noting how much line has to be given out or taken in while keeping the line always just tight, and by accurately measuring at the same time the azimuth of the line, the movements of the ship may be fairly accurately determined at any moment, and especially if the depth be not too great. From the depth at which the lead is lying, and the differences in the length of the line, the horizontal distance which the vessel has moved, may be easily calculated. A simple geometrical construction will give sufficiently accurate results for all practical purposes. *E. g.* suppose the depth of the sea to be 120 metres, the length of the sounding line (to the lead) 150 metres at the beginning of the observation and 180 metres at its end, the azimuth of the line at the beginning N 15° E and at the end N 24° E. The observation lasted 10 minutes.

A distance corresponding to the depth 120 metres, say 120 mm., is marked out on a piece of paper divided into millimetre squares (Fig. 5, *ab*), the distances 150 metres (= 150 mm) and 180 metres (= 180 mm) is similarly marked out from *b* to the perpendicular to the line *ab* at *a*. The points *c* and *d* are thus found, and the distances *ac* and *ad* indicate the horizontal distances the vessel was from the lead at the beginning and end of the observations respectively. If now the two azimuths of the line be marked out on another figure (Fig. 6) and *ac* be marked out along the one line with the corresponding azimuth of N 15° E, and *ad* along the other line (with azimuth N 24° E), it is found that the vessel has moved from *c* to *d* while the observation was being made, and this means a distance of about 47·5 metres (47·5 mm) in 10 minutes, which gives a mean velocity of 7·9 $^{cm.}/_{sec.}$. And the direction of the movement was N 41° E.

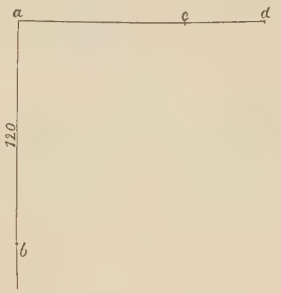

Fig. 5

If the trouble be taken of hauling up the lead every time, and of letting it down again at the beginning of each observation the calculation of the ships movement might be made simpler, as in that case the azimuth of the line will give directly the direction of the ship's movement.

But the differences in the length of the sounding line will give the distance the vessel has moved, the more accurately the greater the angle that the tightened line makes with the perpendicular. It might therefore be advisable to throw the lead out as far as possible from the side of the vessel.

If the ship sway in several directions during the observation, this construction will be somewhat more complicated, and it will also be considerably more difficult to correct the values of the current-observation. It is for this reason inadvisable to continue an observation when it is seen that the ship is beginning to sway in a different direction.

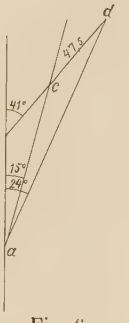

Fig. 6

If the depth of the sea be great, it might be desirable to measure the angle between the sounding line and the perpendicular with the object of determining the average curvature of the line between ship and lead, and thus be able to apply a correction for the error caused by this curvature. But if the curve be approximately the same at the beginning and the end of the observation, the error thus caused will have no great influence upon the final result of the calculation. A more serious consideration

perhaps is the fact that where currents are strong the line may be deviated from its correct azimuth, owing to its resistance to the moving water. But if the line be thin and well tightened even this error may be of no great importance [1]).

How the values obtained by the current observations may be easily corrected graphically by the error caused by the movement of the ship, is mentioned later (see pp. 29—30).

Anchored Boat

Instead of anchoring the ship, a short boat may be anchored; this has less tendency to sway, and it is lighter and much easier to stop in its movements. The swaying of a boat or vessel may be caused either by a current or by the wind. To avoid the

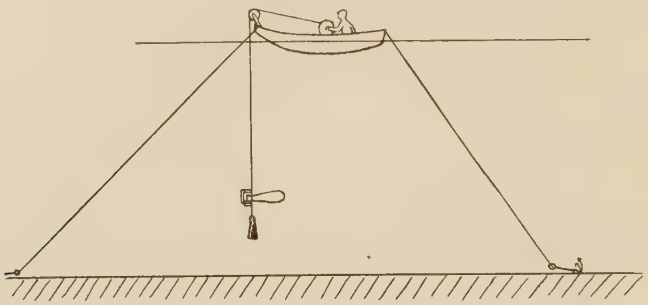

Fig. 7

swaying caused by the current it would be well that the boat were as rounded under water as possible, and without keel. A boat of the type known in Norway as a "pram" would be suitable for the purpose. But such a boat would be more influenced by wind, unless very low on the water. Which type of boat would be preferable must therefore depend on circumstances.

The boat should be anchored by two anchors or grapnels, one fore and one aft, and it may then be kept fairly steady and motion-

[1]) In a paper just received (*Publications de Circonstance* No. 30, 1905) Mr. Rolf J. Witting recommends the determination of the movements of the anchored ship by means of a buoy attached to the anchor, and a line between the buoy and the ship. This method has the disadvantage that the buoy will be more or less moved by the line connecting it with the ship, and these movements cannot be determined. And furthermore if the ship drag its anchor the buoy will be dragged along with it. It would then be better to anchor the buoy with a separate grapnel, as is also suggested by Mr. Witting, and to have no line between the buoy and the ship. The distance to the buoy might then be measured with a line from a rowing boat, or it might even be measured by optical instruments, *e. g.* from the mast of the ship, by measuring with a sextant the angle between the buoy and the horizon. It is, however, always troublesome to anchor a buoy with a line so tight that it cannot move horizontally, and at the same time to take care that it is not carried under the water-surface by the surface-current.

less (Fig. 7). If thin but strong hempen lines be used for the anchors the ends of the lines are easily brought on board the boat from the ship after the anchors have been thrown out. If a proper hand winch with meter-wheel etc. be arranged in the boat a series of current-measurements at different and moderate depths may be taken in a comparatively short time. Before hauling in the anchors the hempen lines may again be brought on board and the anchors hauled up with the steam winch[1]).

This method has the great advantage that no heavy anchors, and no thick lines are required to hold a small boat even in deep waters, and even though the bottom be soft. Very good observations may be taken in this manner, as the boat will sway but little, at least where the conditions are fairly favourable.

Mr. Helland-Hansen has made some current-measurements in the North Sea in this way.

But even with this method, if very accurate observations are desirable, it would be good to have some control, to ascertain whether the boat is moving during the observations.

Anchored Buoy

Description of the Buoy. As the buoy has to stand great pressures, when it is lowered to great depths, it is made of glass balls as used by fishermen for their nets. Each glass ball has a diameter of about 13 cm. and a buoyancy of nearly 1 kilogram. If the buoy is intended for attachment to the end of the line and to have no direct connection with the surface, it is sufficient to sew a suitable number of these balls into an open canvass bag. The bag when filled with the glass balls ought to be given as rounded a form as possible (Fig. 8), in order to offer little resistance to the current and to remain quiet in the water without pendulous movements. It has not yet been quite decided what is the best shape for the buoy. It may probably be convenient to have the glassballs sewed into sections with seven balls in each; as many segments may then be joined together, one on the top of the other, as are required. The size of the buoy will naturally depend on the weight of the line and the instruments used; but under ordinary circumstances a number of 20 or 30 (or 40) balls will suffice.

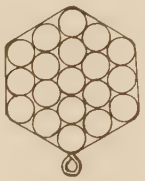

Fig. 8.

When the buoy is intended for attachment to the middle of the line, instead of at its end, and for direct connection by line with the sea-surface, its construction has to be more complicated.

[1]) Steel lines might of course also be used for the anchoring. It would then be advisable to have the lines cut in short pieces, *e. g.* of 50 metres each, and united by small shackles, so that after the anchors had been set out, the lines could be disunited at proper places and the ends brought on board the small boat.

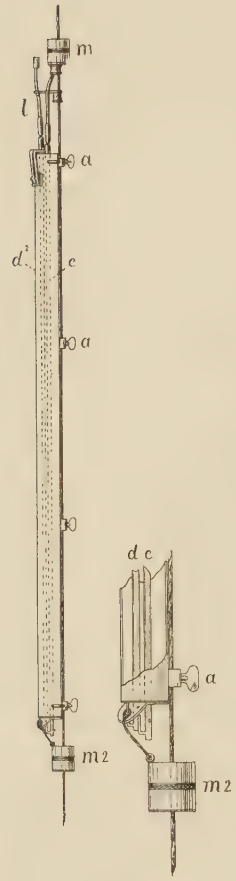

Fig. 9

A Brass-Tube (Fig. 9) 0·9 m. long, is then attached to the line by several jam-screws (*a*). Through this tube run two brass rods (*c* and *d*) which at their lower ends have hooks on which one or two messengers may be suspended. At the upper ends they have movable links (*l*) which can, by special arrangement, be fixed to the line by means of rings and in such a manner, that a small messenger coming from above first knocks down the one rod, and releases one of the messengers suspended under the brass-tube [1]), and a wider messenger coming after knocks down the other rod and releases the second messenger (*m* 2). To two rings on each sides of this brass-tube, two buoys (made of glass balls) can easily be attached by hooks (Fig. 10). A rope (*a*) round both buoys will keep them close together and reduce their resistance to the water.

Attachement of the Current-Meters to the line. The Ekman Current-Meter is easily attached to the line at any place desired, if the line be run through the hollow axis of the instrument. This method has, however, a disadvantage in that the line may be kept inclined owing to the effect of the current on the buoy, and the instrument may then not register correctly. But if the line is not much inclined the inaccuracy thus caused will hardly be of much importance.

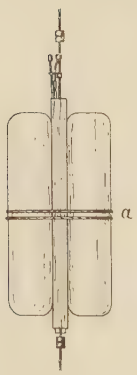

Fig. 10

To suspend the Pendulum Current-Meter freely at any intermediate place on the line, a brass frame shown in Fig. 11 has been constructed, which can be easily attached to the line wherever desired. The brass frame is about 1·7 metre high, and has a horizontal diameter of 0·7 metre. The line is run under catches at *b* and is turned under a hook at *a* (where it may be fastened if desired by a screw). By tilting the frame the line is then carried into the jam-nut at *c*, and made fast by screws. Care has to be taken that the frame is exactly centred, so that the hook (at *d*) from which the

[1]) In Fig. 9 the one rod has been knocked down by the messenger *m* and the first messenger suspended underneath has been released.

current-meter is to be suspended is exactly in the axis of the tightened line, above and below the frame; otherwise the current-meter might be moved, and its registration made inaccurate, if the twisting of the line caused a rotation of the frame.

The current-meter is set working by a messenger *e*, initially suspended at *h*, and released by another messenger *f*, coming from above. This latter messenger may be suspended under the buoy and is there released by a third messenger coming from the sea-surface, or it may be suspended under a clock-work which automatically releases it at a certain moment (see later). The current-meter is suspended as shown in Fig. 11, so that the plane of its own frame is placed vertical to that of the suspension-frame. In this manner the disturbing influences of the frames on the current will have a more uniform effect in all positions of the instrument.

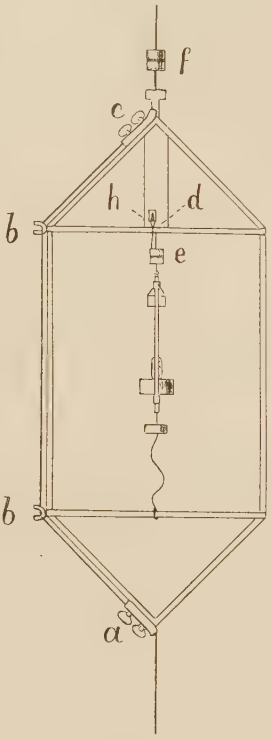

Fig. 11

Anchored Buoy directly connected with the sea-surface by line. The first experiments with this method were made from an anchored vessel. The exact depth was first found by sounding. A heavy lead (20 or 30 kilograms) was then attached to the end of the line, to serve as an anchor. So much line was then let out as was equal the distance above the bottom at which the observation was desired. Here the current-meter (EKMAN's Current-Meter or the Pendulum Current-Meter with frame) was attached, and the line was again let out till the lead was only a short distance above the bottom. Then the buoy with brass tube (see above) was attached to the line, and more line let out until the lead rested on the bottom and the buoy was immersed to its proper depth below the surface. Sufficient line was then let out (Fig. 12) to make the line between the vessel and the buoy perfectly

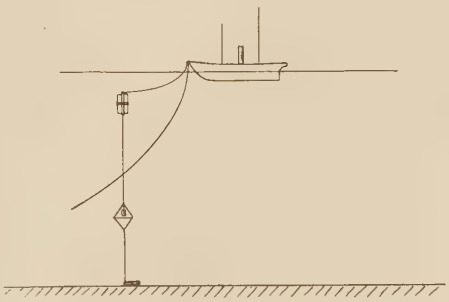

Fig. 12

slack in order to allow the buoy to find its permanent position, and great care had to be taken during the whole observation to keep this line perfectly slack. One or two messengers (one for the Pendulum Current-Meter or two for the EKMAN Current-Meter) were suspended under the buoy and were released by messengers sent down to the buoy from the sea-surface. As the buoy was as a rule carried off some distance from the ship by the current, or the ship swayed away from the buoy, it was generally necessary to go with a rowing boat along the line until vertically over the buoy, in order to send the messengers.

In this way a great many experiments were made, but with comparatively little success. As the vessel generally swayed much, it soon came, perhaps close upon the buoy, and then there was only a short line, or again it moved off far away, and there was much line hanging slack between it and the buoy.

And then it was impossible to prevent the weight of the line from pulling the buoy in the direction of the vessel, in spite of every care exercised to try and keep the line equally slack all the time. To avoid this difficulty an attempt was made with a rowing boat, to keep the line vertical over the buoy during the observation; but even this method was not very successful. It might work tolerably well where there was no surface current to speak of, and then observations of value were actually obtained; but as soon as there was a fairly strong surface current, the buoy was pressed down by this current, and there would always be some length of line above it, which would offer some resistance to the moving water, and consequently form a curve between the buoy and the boat. If an attempt were now made to keep the line vertical over the buoy by hauling on the line this curve would be straightened out, but the buoy would also be lifted, whilst on the other hand if line were given out to keep it slack, the buoy would sink further. It thus proved impossible to keep the buoy in a steady position; the slightest difference in the strain of the line would make it move up or down. This method had therefore to be abandoned.

Anchored Buoy with Clock-work for releasing Current-meter. If a buoy was to be used successfully, it was evident that it must have no connection with the surface, it must be attached to the end of the line and after being anchored, be left entirely to itself to find its own position of equilibrium. For this purpose a clock-work was made, which could be attached to the line below the buoy, for the automatic release of messengers at desirable intervals. To prevent the sea-water from penetrating into the clock-work and thus causing its steel springs etc. to rust, the box of the clock-work was filled with a solution of potash. The first clock-work made for this purpose was,

however, a failure, as it would not work properly in the water; and it was for this reason not possible to make experiments of this kind during the cruise in 1904. During the following winter, however, the clock-work was improved; and Dr. EKMAN succeeded very well with it in the summer of 1905. See EKMAN's description of the method in the Appendix.

This method which can be used for both kinds of current-meters (both with propeller and with pendulum) can therefore be recommended as giving trustworthy results. It has the drawback that each observation requires much time. It has on the other hand, the great advantage, that it can be used without anchoring the vessel.

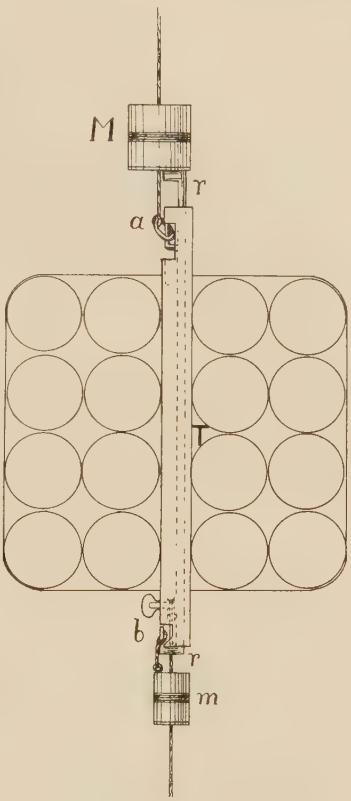

Fig. 13

Observations with Anchored Buoy and the Pendulum Current-meter may also be made, without special clock-work for releasing the messenger, in the following manner:

The buoy used, is made as round as possible, but has a brass tube (Fig. 13, *T*) along its axis, and through this tube a rod (Fig. 13, *r*) can glide up or down. At the upper end of the tube there is an arrangement (*a*) to allow a line with a ring to be attached when the rod is pushed up and the ring is released when the rod is pressed down (*e. g.* by a messenger *M*). At the lower end of the tube, under the buoy, the rod has a hook (*b*) from which a messenger (*m*) may be suspended when the rod is pushed up, but which is released when it is pressed down.

A short bronze or steel line, say 2 or 3 metres long, is attached to the lower end of the brass tube (on the under side of the buoy). The frame with the Pendulum Current-Meter is attached to the other end of this short line; and the sounding line used, is attached to the lower end of the frame. The buoy and the instrument with the end of the sounding line is now placed onboard a boat, on which there is a hand winch with thin steel line. This latter line has at its end a ring which is fixed to the releasing arrangement at the upper end of the brass tube of the buoy (Fig. 13, *a*) as described above, so as

to be able to be released when the rod inside the tube is pressed down. While the vessel is going slowly ahead, or the boat is rowed away from the vessel, so much line is given out, as corresponds to the distance above the bottom where the observation is desired. At that point a heavy lead is attached to the line[1]), and more then given

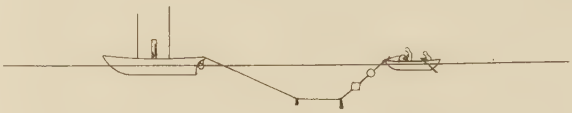

Fig. 14

out while the distance between the ship and the boat is steadily increased, the line being stretched as tight as possible the while. When so much line has been given out as might be sufficient to reach the bottom, the men in the boat may let go the buoy with the instrument (Fig. 14), and they give out the thin line freely taking care however that it does not become so slack, that it may form kinks. At the same time the boat is prevented from approaching the ship; it should rather be rowed in the opposite direction. On board the ship, they give out line with caution, and brake the winch to avoid kinks, while the ship is kept going very slowly away from the buoy.

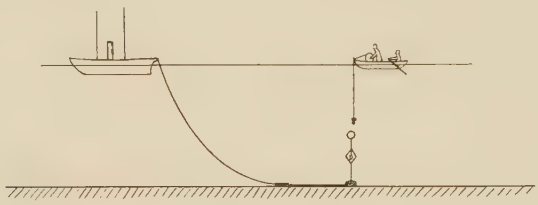

Fig. 15

From the moment the lead has reached the bottom, which is easily felt in the boat, the line from the ship is kept perfectly slack, to prevent jerks on the lead. The boat now tries to find a position as vertical as possible over the buoy, the thin line is tightened and a messenger is sent down which releases the line from the buoy and at the same time sets the current-meter working (Fig. 15). The thin line is hauled on board the boat, and 8 minutes later the instrument and the buoy may be hauled in on board the ship.

This method has the advantage that it probably does not require so much time as the use of clock-work. The buoy is at once brought in its vertical position over the lead, and may be presumed to

[1]) In order to make the line rest on the bottom for some distance from the heavy lead a smaller lead may also be attached to the line a little higher up, see Fig. 14.

be in very nearly its position of equilibrium. But if this should not happen to be the case, the method has naturally the disadvantage, that it is not possible to prevent the current-meter from beginning to work before the buoy has found its final position.

For measuring fairly rapid currents in the upper layers of the sea the Pendulum Current-Meter offers the difficulty that, unless the approximate velocity of the current is known beforehand, it is not easy to select the pendulum, most suitable for the current. And there is of course a limit to the velocities which can be measured by this instrument; very strong currents will naturally carry the instrument itself too much from the vertical. The heaviest pendulum hitherto used will give velocities up to about 25 $^{cm.}/_{sec.}$ but heavier ones might be constructed.

Another difficulty in measuring strong currents by means of an anchored buoy, is of course, that the buoy, unless it have very great buoyancy, will be much pressed down by the current, the line will be much inclined, which may affect the registration of the instruments (especially the EKMAN Current-Meter) and may make the depths of observation very uncertain, since it is never possible to know how much the buoy is pressed down by the current. In such cases it is therefore preferable to take the observations in another way, directly from the sea-surface.

2. Observations from a Drifting Ship or from Drifting Ice

When only fairly accurate measurements of tolerably strong currents are desired, this may be attained even from a drifting ship, if only her drift be fairly uniform, and it be measured simultaneously with the current-observation. This may be achieved as follows: —

The vessel is laid to by a good drift-anchor (Fig. 16, *D*), as big as possible, and with comparatively short wire-rope between anchor and ship in order to prevent the vessel from swaying much.

From the vessel an EKMAN Current-Meter is lowered direct to within a short distance above the bottom where the water moves only extremely slowly [1]). This current-meter is released (by messenger) and set working for exactly the same period as the actual observation

[1]) Nothing is yet known about the velocities with which the water moves in in the deep strata of the ocean; this still remains to be examined. It may be possible that greater velocities than expected will be found, but it seems at any rate probable that the water near the bottom moves only very slowly, at least it would appear so from the current-measurements the writer has hitherto made in Norwegian fjords and in the Skager-Rack.

itself is being taken with another EKMAN Current-Meter in the current nearer the surface. The lower current-meter will give the approximate drift of the ship, during the observation, and if the values obtained by the upper current-meter be corrected by the drift of the vessel as indicated by the lower one, the actual velocity and direction of the current measured may be obtained. In this way a series of current-observations may easily be taken down to depths where the movements of the water are too slow. The only extra work is the lowering of a current-meter down to the bottom and the hauling of it up again for each observation. This may, however, be rather troublesome where the sea is deep; but in that case it might not be necessary to go nearly to the bottom, to find sufficiently quiet water; the waters of layers below a certain depth, may perhaps move sufficiently slowly for the purpose. This may easily be detected by the first observations. If, *e. g.*, the sea be 2000 metres deep and the one current-meter be lowered to 1990 metres and the other to 1000 metres, and it be found that both current-metres give very nearly the same values after having been released and stopped simultaneously it will be sufficient subsequently to send the lower current-meter to 1000 m.[1]) during current-measurements in the higher water-strata.

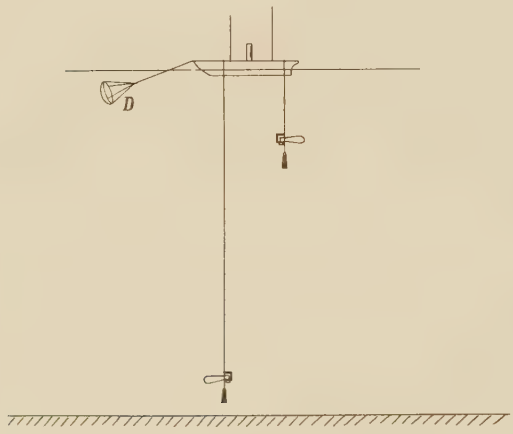

Fig. 16

To ascertain whether the water actually moves very slowly near the bottom, an observation of the bottom current may be taken with the pendulum current-meter and tripod.

Another method for determining the drift of the vessel, is to run a heavy lead (with thin sounding line) at great speed right down into the soft bottom, let it stick there and note the rate at which the line has to be given out while it is kept just tight as described above (p. 18). Where the sea is deep it is, however, difficult to feel

[1]) This method of lowering an EKMAN Current-Meter down into the deeper quiet strata of the sea might also be of practical importance in navigation, especially for sailing vessels; wherever it is desirable to determine the drift of a ship making very slow progress, or laid to, and when astronomical observations are not possible.

whether the lead becomes loosened from the bottom and dragged; an automatic releasing apparatus might therefore be fitted to the lead to release the latter as soon as it comes loose from the mud. The resulting great increase of slackness will then be instantly noticed on board. In this case a single piano wire may be used for the sounding, as the heavy lead is not to be hauled up again and if it should be broken by the strain necessary to pull the lead loose from the bottom, this line is not expensive. In order to avoid the necessity of risking the line by pulling the lead loose from the bottom, it might be arranged so that the lead can also be released by a messenger; but it will then probably be necessary to go back to tbe place where the lead was let down in order to get the line sufficiently vertical to send down the messenger. For soundings of this kind cheap leads of cast iron of special form, made to penetrate deep into the mud, but with arrangements making it difficult to pull them up again, might be used. The single wire has naturally the great advantage of offering little resistance to the moving water, and is therefore not deviated much by currents, but may be stretched fairly straight between lead and vessel. At great depths it is, however, advisable to measure the angle the line makes with the perpendicular in order to determine the error in the length of the line due to its curvature. If the lead be arranged with a tube for taking a bottom-sample, this may be obtained at the same time; and as a sounding ought to be taken at any rate where current measurements are made, this method of determining the drift of the vessel, will therefore give little extra trouble.

As the drift of the ship probably has the same direction during each observation, the azimuths of the sounding-line give directly the direction of the drift. If the sounding-line be not nearly vertical during the observations, the drift of the vessel may be thus fairly accurately determined even in a deep sea; but a great length of line will be required.

If the drift of the ship during a current-observation be exactly known the values obtained directly by the current-meter may easily be corrected by a simple geometrical construction, to give the actual values of the current's velocity and direction.

A few examples will illustrate this; with the EKMAN Current-Meter at 50 metres a mean current-direction of N 30° E and a velocity of 25 $^{cm.}/_{sec.}$ were obtained whilst the drift of the ship was determined by the lower current-meter, S 10° E and 35 $^{cm.}/_{sec.}$ This consequently means that the vessel has moved 35 cm. towards S 10° E during a period when the water at 50 metres has moved 25 cm. towards S 30° W[1]) with respect to the ship. If these two components,

[1]) The direction of the current obtained by the current-meter is the direction from which the current is coming.

AS for the ship (35 mm. long) and *SW* for the water (25 mm. long), be drawn at their proper angles (Fig. 17), it is evident that *aw* represents the actual distance and direction in which the water current has moved in the same time. In this case it is found that the current at 50 metres had a velocity of about 57 $^{cm.}/_{sec.}$ and was running towards S 7° W; its direction was N 7° E.

Fig. 17

Again the upper current-meter lowered to 100 metres indicated on the average S 40° W and 62 $^{cm.}/_{sec.}$, whilst the lower current-meter indicated that the mean drift of the vessel was S 50° W and 48 $^{cm.}/_{sec.}$ during the same period. By the same construction as above, it is found that in this case, the actual current at 100 metres was running with a velocity of about 18 $^{cm.}/_{sec.}$ towards N 10° E (Fig. 18). It is, however, in such a case of essential importance to know the exact directions of the drift and observed current, for if, for instance, there was an error of $\pm$ 10° in the latter, it would mean that the actual current might be running either 24 $^{cm.}/_{sec.}$ towards N 16° W or 14 $^{cm.}/_{sec.}$ towards N 40° E.

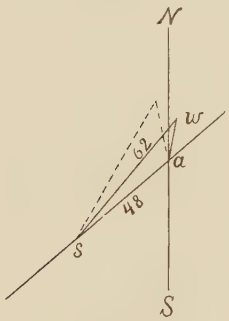

Fig. 18

For observations of this kind it is consequently necessary to have current-meters, that register the directions very accurately. The present Ekman Current-Meter gives indications for every 10°. If double the number of chambers could be arranged in the compass box, *i. e.* for every 5°, it would therefore be an improvement from this point of view.

To make the observations accurate it would naturally be an advantage to continue each observation over a fairly long period. The mean directions for both current-meters have then to be calculated accurately from the positions of all the shots found in the compass-box.

From the drifting ice in polar regions very valuable observations of the currents at different depths of the sea may fairly easily be made in this way. The masses of polar ice have a very steady drift during long periods the velocity and direction of which can be very accurately determined, either by heavy lead and thin sounding line as described above, or by numerous observations with an Ekman Current-Meter lowered to the quiet water near the bottom. As there is no vertical movement due to waves a pendulum current-meter may also be employed for the same purpose if desirable.

The method with lead and sounding line may at any rate be useful as a control of the other method with the current-meter, and if the drift be not too rapid, it has the advantage that it may be em-

ployed continuosly without loss of time during the whole series of current observations; it will furthermore give the velocity of the drift at any moment.

If both methods be used simultaneously, it might also be possible to determine whether there is any current of importance near the sea-bottom. On the ice there is plenty of room, and there need not be any danger of the one line interfering with the other.

As the drift of the ice even on an extensive ocean, changes periodically during 24 hours owing to tide currents, it is essential that it be specially determined during each current-observation even though the winds remain constant.

On Current Observations in general

The currents in the open sea, as well as in fjords with tide, are periodical, and owing to the tide, currents change their velocity and often also their direction more or less regularly during the day[1]). During the drift of the Fram over the extensive basin of the North Polar Sea it was found that the surface currents were, owing to tidal influence, periodic for the day. Single series of current-observations taken at difierent stations are therefore of little value, until complete knowledge of these daily variations themselves shall have been obtained. And single series of observations may easily cause entirely erronous ideas about the horizontal and vertical distribution of currents in a certain area of the sea. If, for instance, at one station the surface currents were measured during their minimum, whilst the deeper currents were measured a few hours later when they approached their maximum, or had even changed their direction, an entirely erroneous picture of the vertical distribution of the currents would result. If at one station the currents at different depths were measured near their maximum, whilst at another station the currents were measurəd at another time of the day, when they had their minimum and had changed their direction, an erroneous picture of the horizontal distribution would be obtained.

The first thing to do at prcsent is therefore to take continuous series of observations at different depths, at least during 24 hours at each station; in order to find out how the currents vary during the day at all depths in the various parts of the sea. Such continuous series of observations should also be taken both at spring-tide and neap-tide and at different seasons, in order to ascertain different effects of the tide. Only in this way will it be possible to determine the actual mean direction and mean velocity of the current during any 24 hours.

[1]) Cf. A. M. van Roosendaal und C. H. Wind, *Publications de Circonstance*, Nr. 26.

After this thorough knowledge of current-variations due to tide, has been obtained for the various stations, it may perhaps be possible to elliminate the effect of the tide itself from any single observation, if only the date and hour of the observation be known. And then, when this is possible, even single series of current-observations at the different stations might become valuable for determining the mean velocities and directions of the currents. But a very great mass of observations will at any rate be required before so much can be attained.

In enclosed seas where there is no appreciable tide, *e. g.* the Baltic, it is of course different, and single series of current observations at different stations, will there give valuable results.

Lysaker, December 29, 1905.

APPENDIX

CURRENT-MEASUREMENTS BY MEANS OF BUOY AND RELEASING CLOCK-WORK

BY

V. WALFRID EKMAN

The positive result derived from experiments described above by Prof. NANSEN, was that it appeared clear, that if reliable measurements of slow currents in the open sea are to be obtained at all, there must be no direct communication between current-meter and ship on the one hand, nor between current-meter and see-surface on the other. To realise these conditions an arrangement as sketched in Fig. 19 was then employed. *C* is the current-meter; above it is a clock-work *A* with an arrangement for releasing, at any particular time-intervals desired, first one messenger and then, if required, another one, which fall down on the current-meter. *B* is a floating-buoy which must be capable not only of carrying the weight of the clock-work, current-meter and wire but at the same time be capable of keeping the latter stretched taut. The whole apparatus is anchored to the sea-bottom by means of a big lead *L* fastened to the line, the latter thence following on to the winch on board.

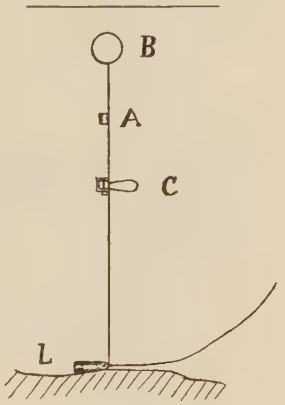

Fig. 19

The buoy is made up of glass balls as mentioned above by Prof. NANSEN (Fig. 8).

The clock-work is shown in Fig. 20 as it appears attached in due position to the line, and in Fig. 21 as it appears when taken out of its cylindrical case. It is made with Anchor action, and with springs and other parts of steel. To prevent rusting, the case *C* (Fig. 20) is therefore made as tight as possible and filled through a hole at *h* (Fig. 20) with an alkaline solution (oil would not do, since it would not mix with the small quantities of sea-water, which will inevitably penetrate into the case). A mixture of glycerine, alcohol and soap

solution has proved to be suitable in all respects [1]). To prevent the solution leaking out, the apparatus is always kept — when not in use — in a metal vessel containing pure water. The axis of the biggest cog-wheel which is driven by the spring is continued through the bottom of the case and ends in the short double-threaded screw *S*. The clock-work may be wound by a key *k* fitting into two holes in the end of this screw.

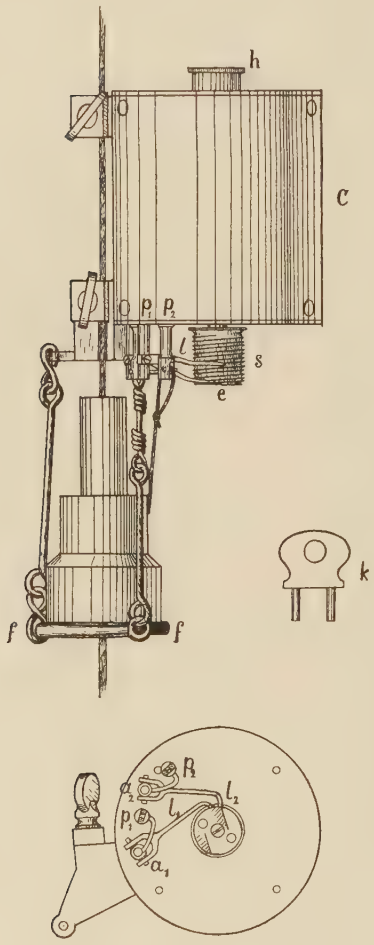

Fig. 20

Furthermore two axes a_1 and a_2 not connected with the clock-work, but acted upon by separate spiral-springs, protrude through the bottom of the case. Each of these axes carries a hook acting as a bolt in the split end of a pillar *p*. Further it carries a lever *l* on a hinch which allows it to remain between two threads on the screw *S* as the latter rotates. The above-mentioned spiral-springs are strained in such a direction that the levers when running between two threads of the screw are pressed against the latter; and as soon as one of them, as a result of the revolution of the screw, reaches the end of a thread at *e* the axis swings round with the result that a messenger hung in the hook is released. As each thread makes 6 revolutions of the screw and the latter makes one revolution in 10 minutes, the instrument can be set to release two messengers at any two desired moments up to one hour, with the one restriction that the time between the release of the two messengers is always 5 minutes or a multiple of 5 minutes.

When the Pendulum current-meter is used, one messenger only is suspended below the clock-work. In the case of the Propeller current-meter the first messenger is not suspended directly from one of the hooks but rests on a fork *ff* which is again suspended from the hook, and on tilting lets go the messenger.

[1]) This mixture was devised by the maker of the clock-work, Mr. Aas, Christiania.

Other arrangements are essentially the same whether the one or the other current-meter be used. Here the use of the Propeller current-meter is described.

A metal wire about 5 metres long and with a thimble at each end, is attached by one end to the buoy and by the other end to the current-meter. The clockwork is attached to the line somewhere between the two and with the screw *S* turned towards the current-meter. The end of the sounding-line is carried from the winch over the meter-wheel and then attached to the lower end of the current-meter [1]). The latter is put in working order, and the messengers are suspended under the clock-work, all this being done while the apparatus

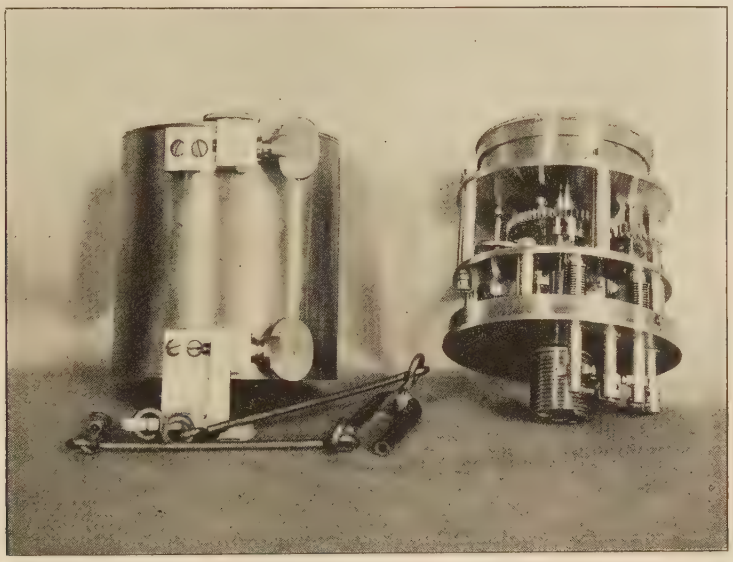

Fig. 21

is lying on deck. While the ship steams slowly ahead steering along the arc of a circle with the meter-wheel on the inner side, the Clock-work is wound and set so as to release the messengers at the desired moments; Buoy, Clock-Work and Current-Meter are let down into the sea. In setting the clock-work it must be borne in mind that the lead must have reached the bottom and the line up to the buoy have had sufficient time to attain its position of equilibrium before

[1]) The pendulum current-meter is hung up in its frame and the two lines attached the one to the upper and the other to the lower end of this frame respectively. The lead of the current-meter itself is connected to the lower end of the frame by a hempen line upon which the whole instrument will therefore hang on reversing the frame. (See Fig. 11.) This hempen line must be flexible and long enough to allow the current-meter to hang quite freely and vertical even if the frame be inclined a little.

the first messenger is released. The line is let out freely as it is pulled out by the buoy, which owing to its resistance to the water remains near the original spot.

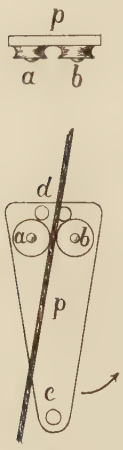

Fig. 22

When so much line is let out as corresponds to the distance above the bottom at which it is desired to measure the current, a lead is fastened to the line, the ship being stopped if necessary. A triangular iron-plate (*p* Fig. 22) with two brass studs *a* and *b* riveted fast at its broader end and with two holes at *d* and one at *c*, is used for fastening the lead to the line. The plate is laid along the line, so that the face bearing the studs is towards the ship, and with the end *c* directed towards the point where the line goes into the sea; the line is brought between the studs as in Fig. 22. Then *p* is revolved $^3/_4$ of a whole turn in the direction indicated in Fig. 22 so that the wire is bent as an *S* half a turn round each stud as in Fig. 23. The plate *p* is revolved half a turn more in the same direction, while

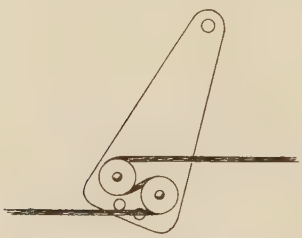
Fig. 23

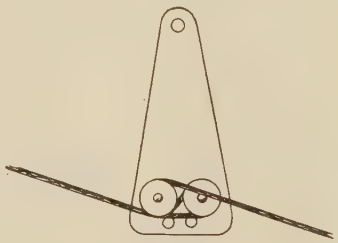
Fig. 24

bending it so that the stud *a* can freely pass by first the one end of the line (Fig. 24) and then the other, without catching them, with the result that both ends of the wire now come up towards *d* between the two studs. The wire is then secured by a string brought through the holes at *d* and knotted over it, by which the lead is also finally attached to *c* (Fig. 25). The whole operation may easily be completed within a minute or less.

While steaming slowly ahead, more line is let out until the lead has reached the bottom. Owing to the buoy the lead sinks rather slowly, and it is advisable to give out line freely to prevent the operation from being slower than absolutely necessary. By occasionally applying a greater force on the brake until a hitch felt on the line announces that the lead has straightened it out, it is easy to find the proper speed and thus to avoid too great a bight and consequent kinks in the line — a very necessary precaution. When no hitch is felt on braking it is known that the lead has arrived at the

bottom. The ship however is not stopped before it has moved some distance farther away from the spot so that there may be a part of the line lying along the bottom. The ship must then lie, as accurately as is possible, at that place — and keep the line steadily slack to prevent the lead from being dragged along the bottom — until both messengers are known to have been released; the line must all the while be kept perfectly slack, so that there is no possibility of a pull on the lead. According as the ship makes inevitable movements one has to take in or give out more line controlling on the meter-wheel and on the direction of the line that one does not come too near to the lead but remains always on the same side of it. The line may never be allowed to hang vertically.

When both messengers are known to have been released the ship approaches slowly towards the lead while the line is hauled in. When the buoy appears again at the surface, the ship moves to it, and the line is wound in carefully, so as not to reverse the current-meter or incline it too much — otherwise the shot indicating the direction of the current may fall out of their compartments [1]). The buoy is fished up with a boat hook and the current-meter then hauled on board from below it. If the line between current-meter and lead is not very short, the latter has to be taken off before the buoy is fished up.

Fig. 25

The whole operation may easily be performed without any difficulty (in good weather). It was found that in water of 70 m. depth about one measurement could be made each hour, if the clock-work be set so that the current-meter were allowed 10 minutes to come to rest after the lead had reached the bottom and be then allowed to run for 10 minutes. Probably it is possible to make measurements more quickly with a little practice.

The Buoy will as a rule not at once stand vertically above the lead on the bottom, even if there be no current; it will only come to this position gradually. And if the current-meter be set to begin the recording while the buoy is still moving, the Current-

[1]) Dr. Carl Forch has proposed a modification of the compass-box, by which this inconvenience may be avoided. A round disc fastened to the top of the compartments inside the compass-box so as to close them, has as many funnels as there are compartments; the funnels are arranged in a circle and protrude one right into each of the compartments. The shot fall through the funnels into the compartments and cannot fall out again on reversing the instrument. On removing the disc, the shot in the compartments can be counted and taken out. If the proposed improvement should be quite effective it would be necessary either to increase the size of the compass-box or to diminish the number of compartments in it.

The Nansen current-meter is, of course, quite free from the above defect.

Meter will of course, give incorrect results. It is therefore of importance to know the time T, necessary for the buoy to take its position of equilibrium. This time will depend, among other thimgs, upon the initial distance of the buoy from its position of equilibrium at the moment the lead reached the bottom. On the other hand it will be practically independent of whether this position of equilibrium is vertically above the lead or not, so long as its angular distance from the vertical is not great.

The following theoretical calculations of T may be of use until there is a definite solution of the question based upon direct experiments. In Fig. 26 B represents Buoy, Clock-Work and Current-Meter together, $OB = l$ is the length of the line between them and the sea-bottom, OX is its direction of equilibrium (supposed vertical) and x is the distance of B from this vertical. P is the buoyancy of B less half the weight in water of the line OB. If it be assumed that the latter always remains rigidly straight, the force P acting on B is then equivalent to the resultant of the forces, dependent on hydrostatic pressure and gravity, moving B towards its position of equilibrium.

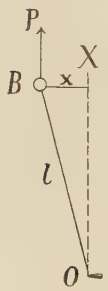

Fig. 26

The resistance R of the water against this motion is aproximately proportional to the square of the velocity of the buoy and therefore

$$R = m\left(\frac{dx}{dt}\right)^2,$$

where m ist a constant. But R is equal to the resultant of the moving forces acting upon B, since the force spent on accelerating or retarding it can be disregarded — i. e. $R = P\,x/l$ and consequently

$$\frac{dx}{dt} = \sqrt{\frac{P}{l\,m}} \cdot \sqrt{x},$$

where the expression on the left hand side is the velocity of the buoy and current-meter as they approach towards their position of equilibrium, This equation gives:

$$\sqrt{x} = \sqrt{x_0} - \frac{t}{2}\sqrt{\frac{P}{l\,m}},$$

where x_0 is the initial distance of B from its position of equilibrium. If by T we denote the time after which the latter will be reached (i. e. after which $x = o$),

$$T = 2\sqrt{\frac{l\,m\,x_0}{P}}.$$

The coefficient m can easily be determined by experiments. For a preliminary estimation of the order of magnitude of T it may be

assumed according to some old experiments that $m = 100\,a$, when a is the sectional area of the buoy in sq. m., and P is measured in kg., dx/dt in m. per sec, l and x_0 in metres.

Clock-work and two messengers weigh together 2 kg., and the current-meter nearly the same. If the distance from the sea-bottom to the current-meter be 500 m., and a steel-wire of 2 mm. diameter (weight 2 kg. per 100 m.) be used, the weight of the instrument and half the wire will be 9 kg. The buoy when made up of 33 glass-balls would have a buoyancy of 26 kg. and consequently $P = 17$ kg.

The buoy of 33 balls may be made to have a section of about $^1/_4$ sq. m. The sectional area the line itself exposes to the current is one square metre, but its resistance against the motion of the buoy is much smaller than it would be if this whole area were connected to the buoy itself. A part of the line which is at a distance l/k from the sea-bottom, will — if the line be supposed to remain straight the whole time — have a velocity which is k times smaller than that of the buoy itself; and will consequently experience a resistance which is k^2 times smaller than if it had taken part in the motion of the latter. As the distance which it has to move is also k times smaller than in the case of the buoy, the resistance which it causes to the motion of the buoy is k^3 times smaller than when rigidly connected to it. By integration it is found that the sectional area of the line has to be divided by four to give the resistance it causes to the motion of the buoy. The whole cross-section to be taken into account is then a $= 0{\cdot}25 + 0{\cdot}25$ or $0{\cdot}5$ square metre, so that the expression for T becomes

$$T = 2\sqrt{\frac{500 \times 50\,x_0}{17}} = 77\sqrt{x_0}.$$

If x_0 be 100 m., T is thus 770 seconds or nearly 13 minutes, after which time the apparatus would have come to absolute rest.

For $l = 100$ m. and $x_0 = 50$ m. it would be $T = 3$ minutes.

These time-periods will, however, probably be somewhat longer owing to the fact that the line is not rigidly straight as was assumed. It is furthermore very possible that the resistance of the thin line per unit of area exposed to the current is greater than in the case of a broader body. In any case the results obtained above, show that the time required is not too great to allow current-measurements to be satisfactorily carried out by the method here described at within some hundred metres from the sea-bottom, and if the buoy will upon the whole take a stable position in the current. The latter question which is very important must be investigated by experiments.

As an example two measurements made at 70 m depth in the

Fig. 27

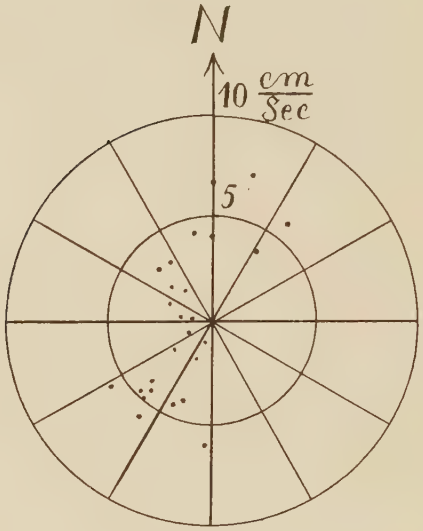

Fig. 28

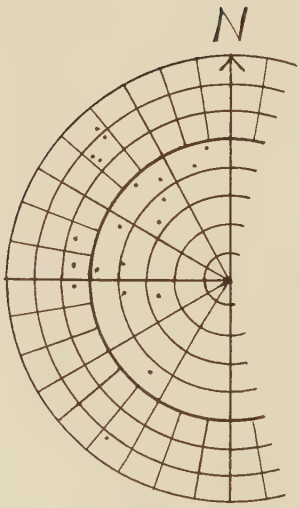

Fig. 29

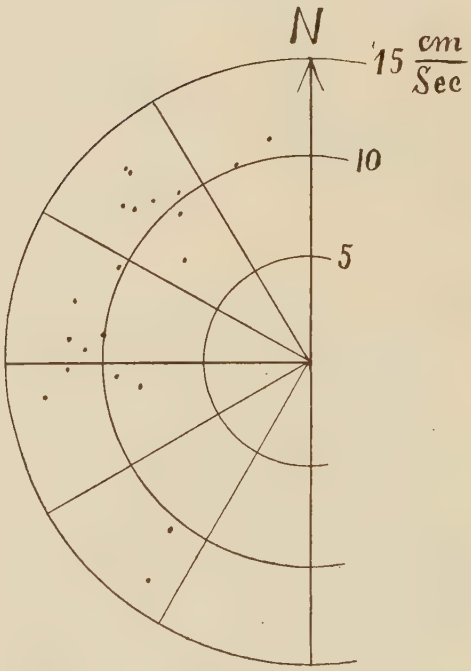

Fig. 30

Puddefjord at Bergen July 19, 1905 with the NANSEN Pendulum current-meter may be mentioned here [1]).

Fig. 27 shows the dots made by the pendulum at 10 a. m. 20 m. above the sea-bottom. The wind was very slight, from the North. The current-meter had 7 minutes to come to rest before the messenger was released by the clock-work. Fig. 28 represents the directions and velocities of the current as calculated from the dots on Fig. 27 (the direction of the dots from the centre of the figure represents the magnectic direction towards which the water was moving). At 11 a. m. a new measurement was made 7 m. above the sea-bottom. At that time the tidal current had begun to run out, in other respects the conditions were unaltered. The current-meter was given 10 minutes to take its position of equilibrium, before the messenger was released. The result of this measurement is represented in Fig. 29 (the original dots), and Fig. 30 (velocities).

Improvement of the Ekman Current-Meter

A small alteration which has recently been made in the construction of the current-meter described in Publications de Circonstance No. 24, may be noticed here.

In instruments of this pattern hitherto used, the dial-plate has two doors; on opening them a wheel with 20 small compartments arranged in a circle is disclosed. The shot which are eventually to be dropped down into the compass-box to indicate the current direction, must be laid one in each of these compartments, an operation it is no doubt ordinarily somewhat inconvenient to carry out in bad weather.

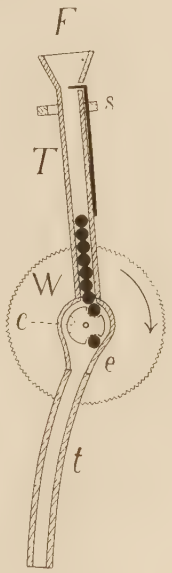

Fig. 31

This arrangement is therefore now replaced by another shown on about half scale in Fig. 31. *W* is one of the dial-work wheels, which is put in motion directly by the propeller and makes one revolution for each hundred revolutions of the latter. Its axis is at one place widened to a cylinder of 6 mm. diameter in which 3 half-spherical cups *c* are cut, and this cylinder moves inside a cylindrical encasement *e*. Two brass tubes *T* and *t*

[1]) The experiments made on this occasion were of only a preliminary nature and had for object chiefly the testing of the handiness of the apparatus, the time available being too short for a systematic investigation of the reliability of the measurements. The propeller current-meter was also used repeatedly with success but with negative result, since the currents were too slow. The propeller made but one to two revolutions a minute, whilst to work satisfactorily it must revolve at least 3·5 times a minute (corresponding to a velocity of 2 cm. per second).

are attached to the encasement, so as to open respectively just above and just below the cylinder bearing the cups *c*. The tube *T* serves as magazine for the shot. As the wheel *W* revolves and one of the cups *c* passes the lower end of *T* a shot drops into the cup; on further revolution the shot is carried round in the cup, and on reaching the upper end of *t* drops through it into the compass box. In this way 3 shot fall into the compass box for each hundred revolutions of the propeller.

A small spring *s* protruding into *T* at its upper end, just below the funnel *F*, prevents the shot from falling out even if the instrument be reversed. When *T* is being filled with shot this spring is pressed aside by the finger.

As it is a necessary condition for the satisfactory working of the mechanism just described, that the shot shall all be of equal size, a double sieve can be supplied by the Central Laboratory for separating out the right size. The shot might also be replaced by Bronze-balls such as are used for ball bearings. For special investigations where it is desirable to study the change of current direction with time Professor NANSEN has suggested that each ball may be identified by engraving or plating in a different way.

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